PITSTOP

A TYPICAL FORMULA ONE motor race will cover about 300 km and take over one and a half hours, but the winning driver may well be decided during those crucial few seconds that his car is standing still – in the pitstop.

The pitstop is an essential part of motor racing and is carried out in a special lane that runs off the main track. It is where the car pulls in for tyre changes, minor electrical adjustments or even major structural repairs. An expert team of mechanics can change a complete set of tyres and have the car back in the race in less than ten seconds – possibly the crucial difference between victory and defeat.

With today's highly specialized racing tyres – known as slicks – it is routine for a car to make at least one pitstop to change tyres during a race. Racing slicks are very different to normal car tyres. They are usually smooth, with no tread pattern, and maintain their grip by 'burning off' their soft rubber and depositing it on the track. This means that they wear out very quickly; the more powerful the car and the hotter the conditions, the more often the tyres need changing. A tyre will only be at its best for perhaps a handful of really hard-driven laps before it starts to lose its slight edge, so changes will be needed.

Qualifying laps

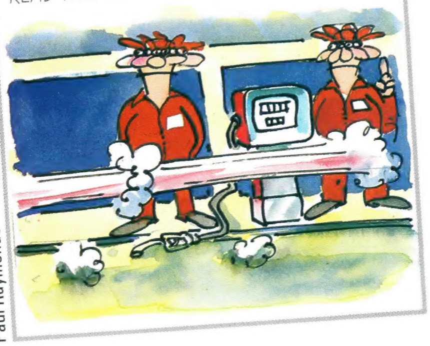
Special qualifying tyres are used the day before the race to decide starting line-ups on the grid – the fastest qualifier starts at the front and so on. The qualifying tyres will complete

Nigel Mansell has his wheels changed during practice. A portable computer screen gives drivers details of the fastest qualifying times and the race leaders (inset, left).

Vandystadt/Allsport

Just amazing!

QUICK STOP
AMERICAN DRIVER BOBBY UNSER HAD HIS CAR REFUELLED DURING THE 1976 INDIANAPOLIS 500 RACE IN JUST FOUR SECONDS - FASTER THAN IT TAKES TO READ THIS SENTENCE!


Paul Raymonde

perhaps one or two laps to get fully warmed up, then do one really fast lap to set a qualifying time, followed by one slowing-down lap, after which they will be discarded.

Another situation when tyres need changing is if the track gets wet because of rain, or alternatively dries up after a wet start. In wet conditions, cars use special 'rain tyres' that have a tread pattern similar to normal road tyres. This helps them dispel surface water to stop the car from aquaplaning - skidding on a thin layer of water.

If it has rained before a race, the track will be wet at first but may dry up later, so the driver will want to change to dry-weather slicks, which are faster, as soon as possible. Similarly, if the driver is using slicks when it starts to rain, he will want to switch to rain tyres as soon as he feels that he is losing grip. Whatever the reason for a tyre change, it must be done as quickly as possible. Two laps before a car makes a pitstop, the driver alerts his team of mechanics via his short- wave radio system

Pit procedure

Before each race, the mechanics lay out a distinctive trail of coloured tape leading to the point where they want the car to stop. When it pulls up, they spring into action. The team may consist of up to 20 men: three mechanics per wheel, two quick-lift jack operators, a time-keeper, lap-scorer and signallers.

Each one has a specific job to do. Of the three men at each corner, one removes the wheel using a high-speed pneumatic spanner, another lifts off the wheel and the third man puts on the fresh wheel. During the stop, the driver is in contact with his chief mechanic or team manager through their radio headsets. With the roar of the engine and the whirring of the air-powered spanners, it would be impossible to communicate by any other means.

As soon as the new wheels are bolted in place and all four corner teams signal that they have finished, the jacks are lowered and the car is off on its way back into the race. A smooth tyre change can be completed in seven or eight seconds; a tricky wheel nut or loose wire could cost the driver precious minutes.

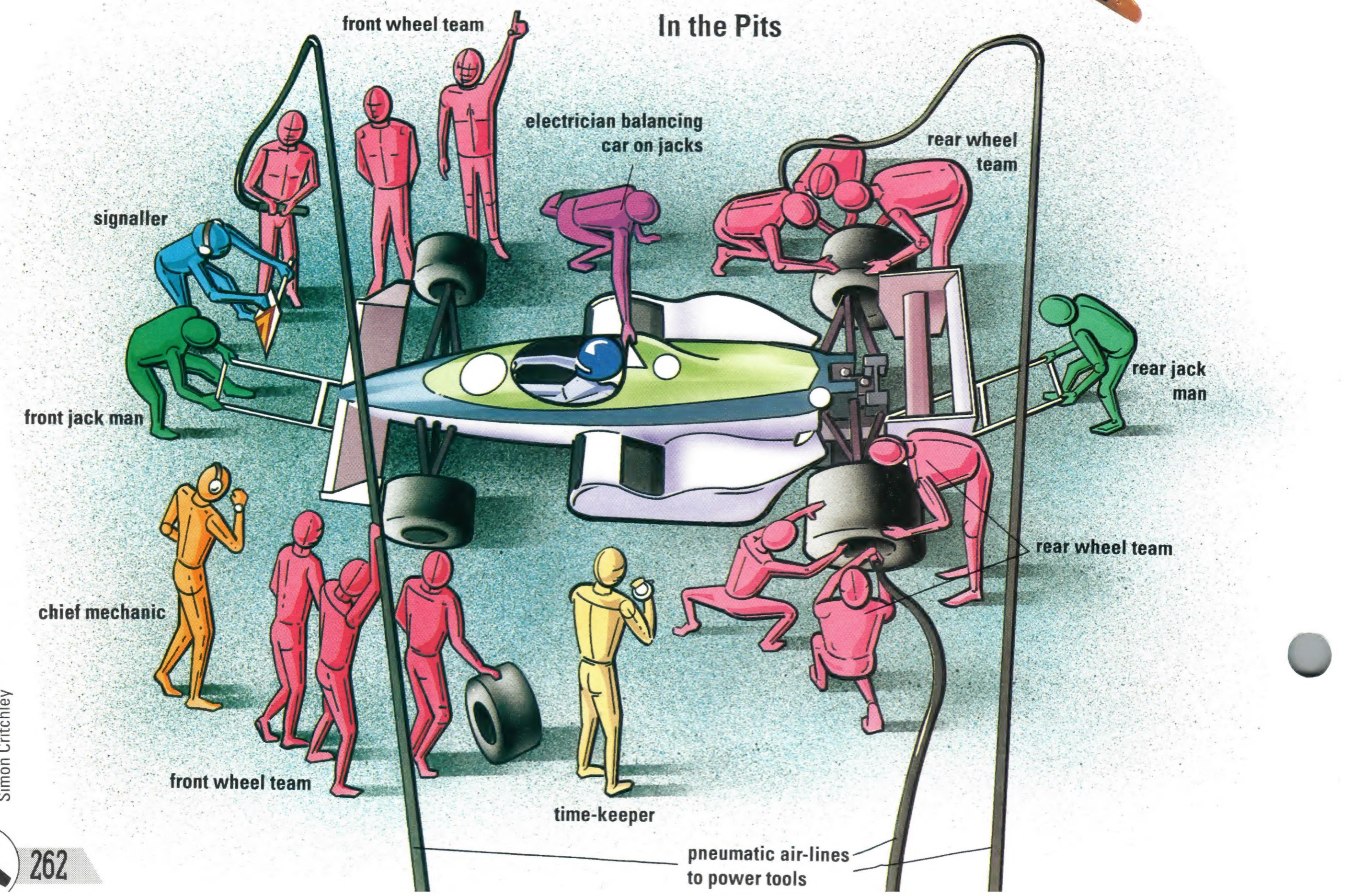
Emergency repairs

All sorts of emergency repairs can be carried out in the pits, ranging from a replacement visor for the

A bodyshell *replacement for a Lotus during the German Grand Prix in 1987. The team mechanics keep enough spare parts to replace a whole car if necessary, and bodywork repairs such as this one can be done in a matter of seconds – any longer and the driver loses all hope of winnning.*

Taillade/Colorsport

In the Pits



Simon Critchley

driver to fitting a new nose cone on the front of the car. All teams carry at least one spare car and enough body panels to rebuild a whole car if necessary!

One routine pit stop task which has recently led to controversy and danger is refuelling. Early cars could not carry enough fuel to power the vehicle around the track for the entire race. Each driver had to stop to fill his fuel tanks at least once, sometimes twice, during a particularly long race.

Zooom Photographic

Zooom Photographic Ltd

***Racing tyres** are known as slicks. They are smooth and do not have tread patterns like normal road tyres.*

***Wet weather tyres** have treads that dispel surface water and help the car maintain its grip in the rain.*

start of the race and able to build up a fast time before stopping to refuel. The techniques of refuelling were refined so that the least possible time was spent in the pits. In 1994 a dramatic explosion in the pits when the Benetton car was refuelling led to an inquiry into refuelling equipment and led many teams to rethink their fuel strategy.

Compoint/Colorsport

By the late 1980s fuel efficiency had increased to the point that a vehicle could carry enough fuel for an entire race. However, this soon led to other problems.

Cars were so heavily laden with fuel at the start of a race that they would scrape the ground on the slightest bump in the track surface. This meant that cars had to be fitted with metal studs to protect their underside and these produced great showers of sparks when they struck the ground.

The weight of fuel also made the vehicle perform relatively sluggishly at the start of the race and many drivers complained that they were unable to exploit an early advantage due to poor acceleration.

As a result racing teams returned to refuelling during a race. This meant that the car was lighter at the

Onboard computers

However, the car's computer is now considered an essential piece of equipment. Apart from fuel read-outs (which are usually correct), the computer can automatically adjust the suspension, so that the car maintains a constant height off the ground, whatever load it is carrying. As the race progresses and fuel is used up, the car becomes lighter and tends to rise higher off the ground, lessening its road-holding abilities. But the computer calculates the weight loss and relaxes the suspension.

Pascal Rondeau/Allsport

***'Electric blankets'** are used to get replacement tyres up to the optimum racing temperature required according to weather and track conditions.*

***Tyre technicians** cutting treads into slicks. During a Grand Prix race meeting the cars may use up to 1700 tyres, of which 600 could be rain tyres.*

VIEW RACING AROUND THE WORLD

Vandystadt/Allsport

Jet skis are great fun, but they are used in serious races too. Riders wear motorcyclist's protective clothing in case they should hit the water at high speed.

The Paris-Dakar rally is raced over 11,000 km, mainly in Africa. This DAF truck was pulled out of the race in 1988 after another DAF driver was one of three rally drivers killed. The race has now been severely curtailed, with fewer entrants than before for safety reasons.

Dragster motorcycles are very different to road machines. The low-slung frame helps reduce air resistance and so increases speed.

Jon Nicholson/Allsport

S Compoint/Colorsport

Dune buggies are designed to be driven over sand, so they are ideal for racing in desert rallies.

Vandystadt/Allsport

Kenyan tribesmen watch the latest high-powered Toyota turbo in the shadow of Mount Kilimanjaro, during the Kenyan safari rally. The drivers cross some of the world's most spectacular scenery, but rarely have time to take in the view at speeds of 150 km/h.

R Klein/Sipa Sport/Colorsport

Snow scooters are used for getting around ski slopes quickly. Powered by motorcycle engines, they are capable of speeds of up to 50 km/h.

Vandystadt/Allsport

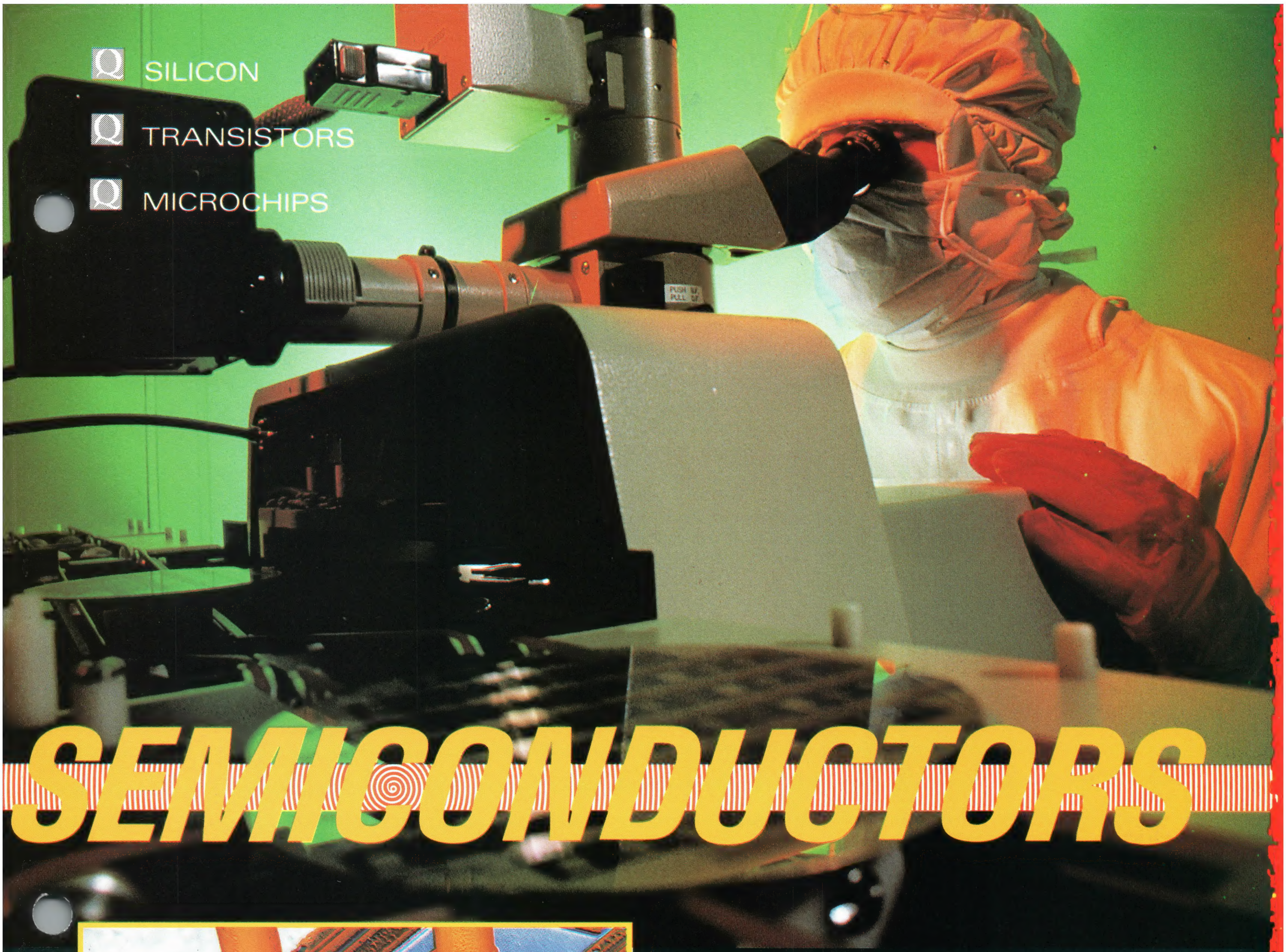
A motorcycle and sidecar at the start of the Pharoah's Rally in 1988. This race around Egypt has separate sections for cars, trucks and motorcycles.

M Montange/Moto Journal/Colorsport

SILICON

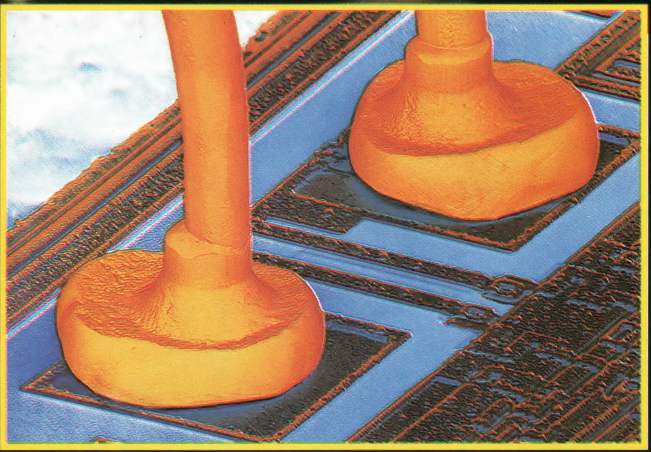
TRANSISTORS

MICROCHIPS



SEMICONDUCTORS

ZEFA



Dr Jeremy Burgess/Science Photo Library

Microchips are etched directly on to semiconducting materials – usually silicon. Thousands of tiny circuits exploit the electrical structure of the semiconductor. The minute circuits and connections (inset) have to be checked under a microscope.

SEMICONDUCTORS HAVE revolutionized our lives. These materials have made it possible for scientists to devise first the transistor and then the microchip, vital components found in today's electronic machines.

Materials that conduct electricity easily are known as conductors. They are mostly metals, although one non-metal, carbon, is an excellent electrical conductor.

Conductivity

All materials conduct electricity to some extent, but conductors do so one million million million times better than non-conductors such as plastics and ceramics.

In between these two extremes there are semiconductors, which conduct electricity better then plastics but less well than metals and have properties that lie between those of a conductor and a non-conductor.

Heat treatment

One important way in which a semiconductor differs from a conductor is its reaction to heat. When the temperature of a conductor increases, less electric current flows because its resistance is higher. However, heating a semiconductor has exactly the opposite effect – more electricity flows through the material.

Semiconductor materials include the elements germanium and selenium and the compound lead telluride. But the semiconductor material that is mostly widely used today is silicon, the element whose name is now used to describe the most important part of the electronics industry – the manufacture of integrated circuits, or silicon chips.

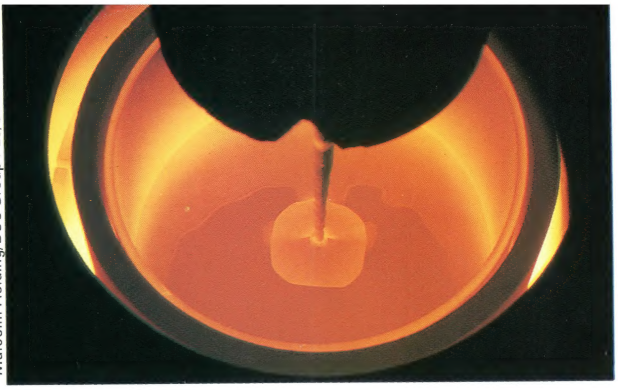
To understand how a semiconductor works, it is necessary to know what an electric current is. In a metal, each atom has some electrons that are easily released. So there are always a number of electrons that are free to wander among the latticework of atoms. If a source of electricity, such as a battery, is connected across a metal wire, the 'free' electrons, which are negatively charged, are attracted to the positive terminal of the battery and there is a flow of electrons along the wire. This flow of electrons is what we call an electric current.

Free electrons

In a non-conductor the atoms are constructed in such a way that there are no 'free' electrons available, and so connecting a non-conductor to a battery does not produce an electric current. In a semiconductor, the atoms are very like those of a non-conductor. However, a few electrons do have enough energy to break free from their atoms and become available for carrying electricity. Heating

such a material puts more energy into the system and more electrons break free, which is why the conductivity of a semiconductor increases as its temperature increases.

As in a metal, free electrons in a semiconductor move towards the positive terminal. This results in what is known as n-type conductivity. At the same time there are spaces, or holes, left in the atoms. These behave in a more complicated way, but they can be thought of as having a positive charge and drifting in the opposite direction to the electrons, a phenomenon known as p-type conductivity. The total electric current that flows through the semiconductor is the combined effect of the electron current and the hole current.


Malcolm Fielding/BOC Group PLC/SPL

A silicon chip *is made from a silicon crystal. A crystal 'seed' is suspended in molten polysilicon. It is rotated and, slowly, a crystal grows, reaching 75-100 mm in diameter and up to 1 metre in length. The thin chips are cut from this.*

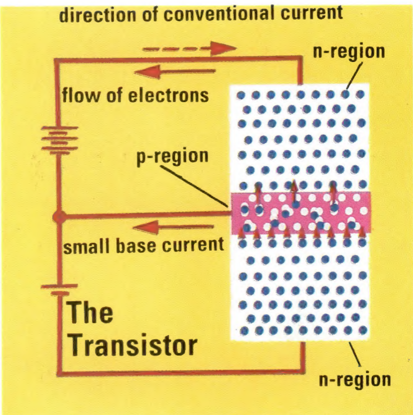
Pure semiconductors

Pure, or intrinsic, semiconductors are not particularly useful, because at normal temperatures they only conduct very tiny amounts of electricity. However, the conductivity of a semiconductor can be greatly increased by adding a tiny amount of another element as an impurity. Two kinds of semiconductor can be produced in this way. For example, when silicon is 'doped' with a small amount of phosphorus, some of the silicon atoms become replaced by phosphorus atoms. Phosphorus has more electrons available than silicon and this results in an n-type semiconductor with extra electrons. Antimony can also be used to make an n-type semiconductor. Aluminium, on the other hand, has fewer available electrons than silicon. Doping silicon with aluminium therefore produces a semiconductor with extra holes; that is, a p-type semiconductor.

Rectifiers

Placing an n-type semiconductor against a p-type semiconductor forms a p-n junction. This is the basis of a device known as a rectifier, which is used to convert alternating electric current into direct current. Placing two p-n junctions back to back creates a transistor, of which there are two possible types – p-n-p and n-p-n. Transistors can be used as electronic switches or for amplifying electrical signals.

These and other electronic devices can be created on the surface of a small piece of silicon by 'doping' selected areas with the appropriate impurities. Adding suitable metal connections creates an integrated circuit, known as a silicon chip. Semiconductors are also being used to create very small, stable lasers for use in optical-fibre telecommunications systems.



Mark Franklin

In a transistor, *semiconductor layers are arranged so a small current in the P-layer controls a larger current in the device.*

SUPERCONDUCTORS


Ivaldi/Jerrican

As the temperature of a material approaches absolute zero (0 K or -273°C), its resistance to electrical current drops to zero and it becomes a superconductor. Mercury, for example, becomes a superconductor below 4.2 K, lead superconducts below 7.2 K and niobium-germanium alloy superconducts below 23.2 K. A key test of superconductivity is that a superconductor floats in a magnetic field (see above), a phenomenon known as the Meissner effect. Silicon chips whose circuits are made of superconducting materials will be able to carry electrical signals very rapidly, meaning that computers would be able to process information faster than ever before. However, it is difficult to cool materials to such low temperatures and the problems increase as temperatures get closer to absolute zero – 0 K is actually impossible to reach. But scientists have recently discovered complex materials containing the element thallium that superconduct at the much higher temperature of 125 K. In the future, some materials may superconduct at around 200 K (about -17°C). However, there are still problems, and it remains to be seen if any of these 'warm' superconductors will prove useful.

Just amazing!

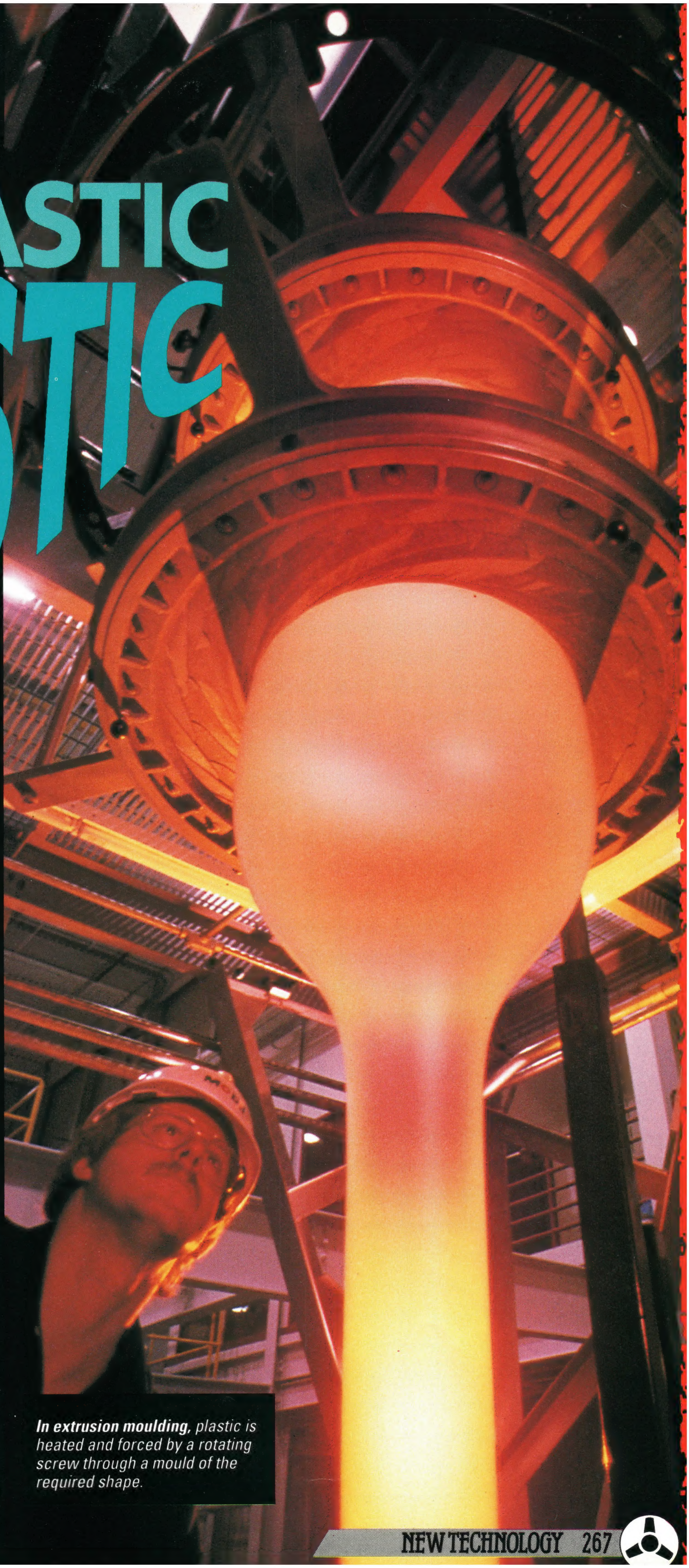
BUSY BEES

AMERICAN SCIENTISTS ARE ATTACHING SILICON CHIPS TO A STRAIN OF KILLER BEES IN AN ATTEMPT TO MONITOR THEIR MOVEMENTS.

Paul Raymonde

POLYMERIZATION
SHAPING PROCESSES
ARTIFICIAL FIBRES

FANTASTIC PLASTIC



In extrusion moulding, plastic is heated and forced by a rotating screw through a mould of the required shape.

ZEFA

PLASTICS ARE AMONG THE most versatile of modern materials and in many cases are better than natural ones. They are now used in place of wood and metals in a vast range of products and household equipment. Items such as photographic film and non-stick surfaces could not be made from anything but plastic.

When we describe something as being plastic we mean that it can be moulded or formed into any shape. Plasticine, for example, is a truly plastic material. On the other hand, many of the materials that we know as plastics are hard and inflexible. Such plastics can be softened and moulded by applying heat, but so too can other hard materials, such as glass and metal.

Carbon atoms

The thing that distinguishes plastics from other synthetic (man-made) substances is the fact that their molecules are based on long chains of carbon atoms. Most are made of chemicals obtained from crude oil and natural gas, such as ethylene or ethene proplylene, butylene, benzene and methyl alcohol. Ethylene is used to make a range of plastics, including polythene polyvinyl chloride (PVC), polyvinyl acetate, polystyrene and acrylic. Such carbon-containing chemicals are known as organic chemicals, because they were first discovered in living organisms.

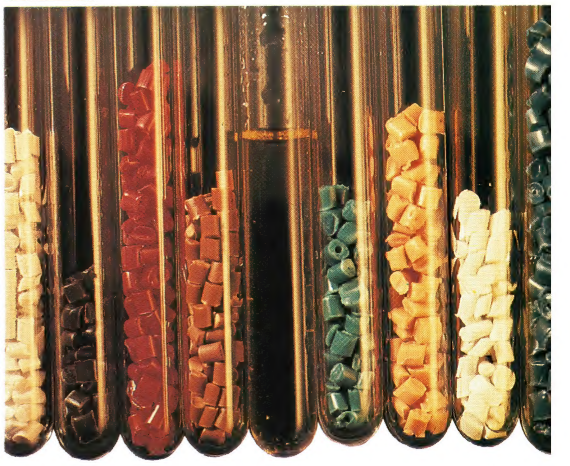
Plastics can be divided into two main groups – thermosoftening plastics (also called thermoplastics)

and thermosetting plastics. 'Thermo' comes from the Greek word meaning 'heat' and these two terms describe what happens when plastics are heated. A thermosoftening plastic softens when heated and becomes hard again when cooled. This is because its long-chain molecules become flexible and capable of sliding over each other. Thermosoftening plastics, such as polythene, can be shaped and reshaped many times.

Softening occurs at different temperatures in different plastics. For example polythene begins to soften when dipped in boiling water. Nylon remains hard in boiling water but can be softened by heating it over a flame. PTFE remains hard until it reaches a temperature of just over

US Dept of Energy/Science Photo Library

***Crude oil** is divided into many components, or fractions, by distillation. One of these – naptha – contains the chemicals used in the manufacture of plastics. Plastic for moulding is supplied in the form of powder, liquid, paste or granules (below).*

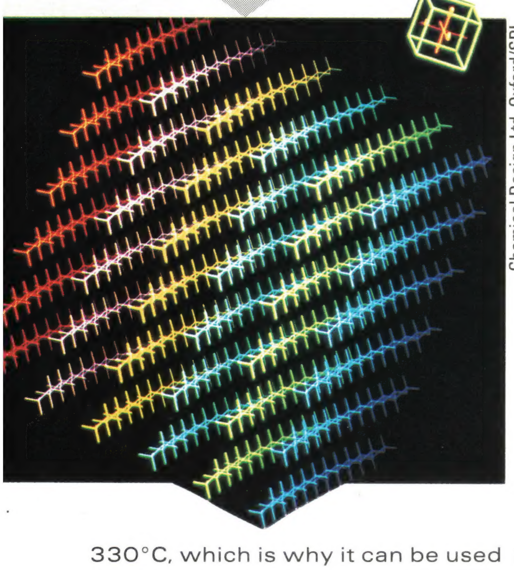


Paul Brierley

Tony Stone Photo Library

***In an oil refinery,** petroleum is heated and fed into a 'fractionating tower' where the various components separate out at different levels according to their boiling points. The gases evaporate and rise to the top, while the heavier oils are collected at the bottom.*

***Ethylene,** a chemical derived from petroleum, is turned into polythene by polymerization. This transforms small molecules into long chain molecules.*



Chemical Design Ltd, Oxford/SPL

330°C, which is why it can be used for non-stick surfaces on pans.

A thermosetting plastic, on the other hand, can be shaped only once – at the time that polymerization takes place. This is the process of joining up short molecules to form long ones. All plastics are polymers created by the polymerization of simple organic chemicals. When a thermosetting plastic is heated, chemical reactions take place – cross-linking bonds form between the long-chain molecules, holding them together rigidly in a three-dimensional network. If a thermosetting plastic is heated, the only result is that more cross-links form and the plastic becomes even more rigid.

Heat-resistance

Thermosetting plastics are used to make heat-resistant objects, such as light fittings, saucepan handles and kitchen worktops. They include such plastics as Bakelite (also called phenol-formaldehyde or phenol-methanal), polyurethanes, polyester resins and epoxy resins.

One of the most useful properties of plastics is the fact that they can be formed into almost any shape and can therefore be fashioned into a wide range of different objects. Several forming methods are used:

- Extrusion is the simplest. Hot plastic is forced through a specially shaped hole, or die, to form a long piece of plastic with the same cross-section all the way along its length. Plastic pipes, curtain rail and thick plastic sheets are made in this way
- Calendering is used to make thin plastic sheets – hot plastic is squeezed between a series of rollers
- Injection moulding is a widely used process whereby hot plastic is forced through a nozzle into a mould. The plastic fills the mould completely and forms a solid object, which is removed by separating two halves of the mould. This produces mouldings of very high quality and great accuracy. It is used to make objects such as vacuum cleaners, bottle crates and protective helmets.
- Compression moulding, in which hot plastic is squeezed into shape by bringing the two halves of the mould together, is used to make objects such as bottle tops and toilet seats
- Blow moulding is used for hollow objects such as plastic bottles. A piece of hot plastic tubing is placed between the two halves of

Just amazing!

TIME FOR A CHANGE

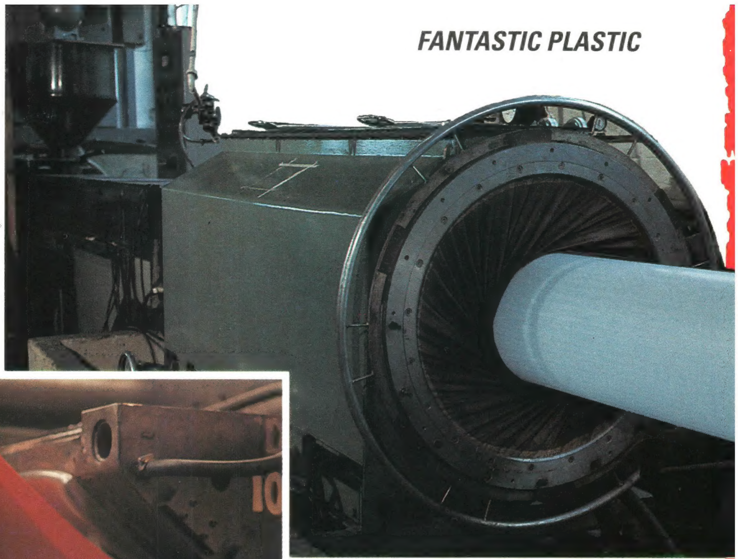
IN THE FUTURE, CLOTHING MANUFACTURERS WILL BE ABLE TO CREATE CLOTHES FROM SYNTHETIC FIBRES THAT CHANGE TO WHATEVER COLOUR THE WEARER WANTS

Paul Raymonde

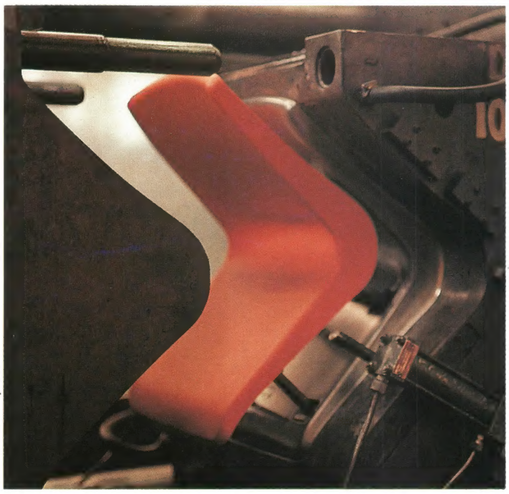
the mould, which are then pushed together to trap a section of tube inside. Air is then blown into the mould, forcing the tube to take the shape of the inside of the mould

- Vacuum-forming uses air pressure in a different way. A sheet of hot plastic is held in a frame and pulled down on to a mould by suction. Acrylic baths, boat hulls, the linings of refrigerators and plastic egg boxes are made in this way
- Rotational moulding is the technique used for large containers with thick walls, such as water tanks and dustbins. Plastic granules are poured into a mould that is rotated on two axes at low speed. The mould is heated and the plastic melts, forming a skin that sticks to the inner surface. While still rotating, the mould is cooled by air or water spray or a combination of both. Rotationally moulded products include fuel tanks, toys, surfboards and storage tanks.

All thermosoftening plastics can be made into fibres – the long chain molecules simply align themselves in one direction. Artificial fibres are generally harder wearing than



***Polythene pipes** are made in an extruder. Plastic granules are forced through a heated barrel by a revolving screw, which injects the softened plastic through a cylindrical die.*



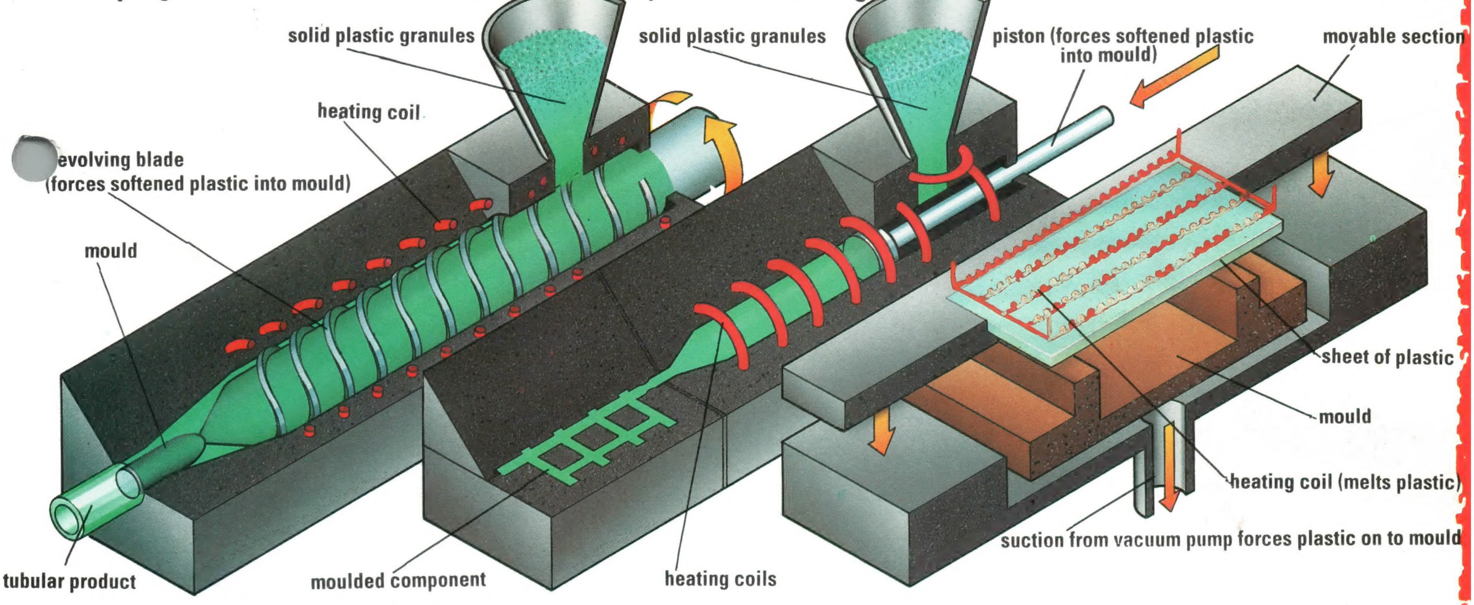
Paul Brierley

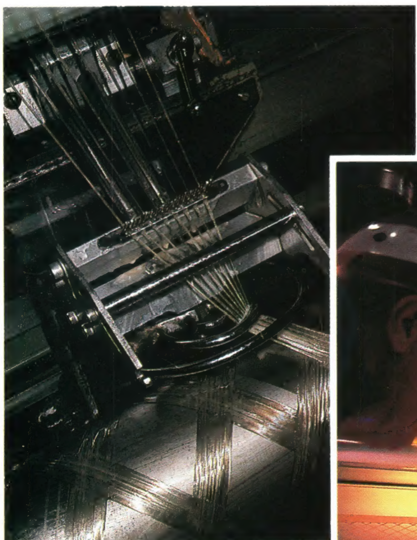
***Plastic chairs** are shaped by means of injection moulding – plastic is forced through a heated barrel into a steel mould.*

***Most plastic-shaping methods** involve softening the material by heating before forcing it through a mould. Thermoplastics are easiest to shape because they stay molten while they are hot.*

Ron Oulds/Robert Harding Picture Library

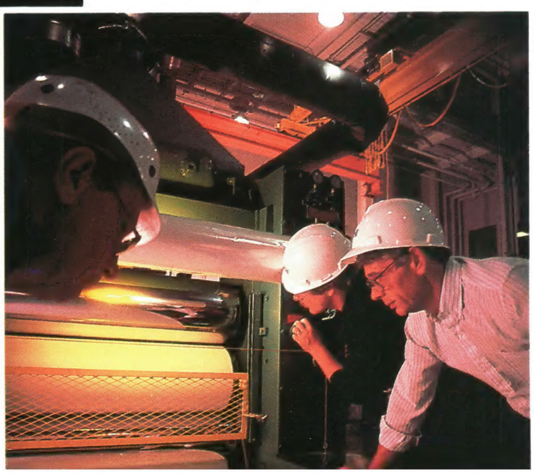
Shaping Processes





Paul Brierley

***Calendering** is a method for making sheeting by passing plastic through heated rollers. Plastics can be strengthened by adding fibreglass (left).*



ZEFA

natural ones such as wool and cotton. Plastics such as polypropylene and nylon produce strong fibres that are widely used. Some thermosetting plastics are drawn out in the form of fibres, such as polyacrylonitrile ('acrylic' fibres) or copolymer, formed from acrylonitrile and vinylacetate.

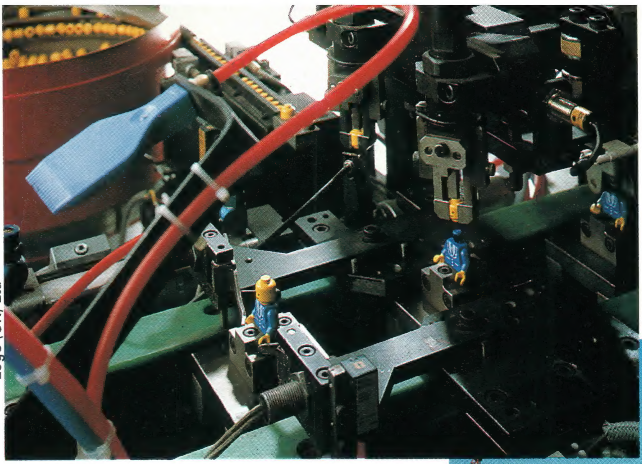
Strong fibres

Among the strongest fibres are those that belong to a group known as aramids. These are derived from nylons (polyamides) and differ from other plastics in that they char rather than burn. They are immensely strong materials; the tough fabric Kevlar is based on aramid fibres and is used to make bullet-proof clothing.

Another, completely different

form of plastic is plastic foam. This is simply a plastic that has been filled with bubbles of air before being allowed to become solid. Polystyrene is commonly formed as a foam to make insulation panels and packing materials. Other plastics used to make foams include polyethylene and PVC. Polyurethane foams are employed in building and in the manufacture of furniture. A major drawback, however, is that they give off potentially lethal, choking fumes if they catch fire.

Transparent plastics are made into lightweight, shatter-free substitutes for glass. Acrylic, sold under such trade names as Perspex and Diakon, is used to make aircraft cockpit canopies, secondary double glazing and lenses. It can also be coloured to produce such things as brake-light covers for cars.



Lego (UK) Ltd

LEGO *components are produced by pressure and vacuum moulding. It takes between 7 and 10 seconds to mould, cool and extrude one batch of LEGO pieces.*

Dr Jeremy Burgess/Science Photo Library

***Plastic roads** have foundations made of polystyrene blocks. These are covered with a thick sheet of plastic and capped by a normal tarmac road surface.*

COMPOSITES

Plastics are often mixed with other materials to form what are known as composites. Chipboard, for example, is a composite formed from wood and urea-formaldehyde resin. A small amount of urea-formaldehyde is also mixed with wood fibres in the manufacture of paper towels. The resin holds the paper's fibres together, giving it extra strength when wet.

One of the most common composites is glass-reinforced plastic (GRP) or fibreglass. Polyester resin is reinforced with glass fibres woven into a mat or fabric to produce a very strong material that is used to make boat hulls, car bodies and aircraft seats. GRP is also used in the nose-cone of the supersonic airliner Concorde.

Asbestos, cotton and nylon can also be added to plastics to improve strength and heat resistance.The most widely used composite is carbon-fibre reinforced plastic (CFRP), made by embedding carbon fibres in an epoxy resin. Carbon composites are used to make sports equipment, artificial limbs and aircraft parts.

See-through plastic

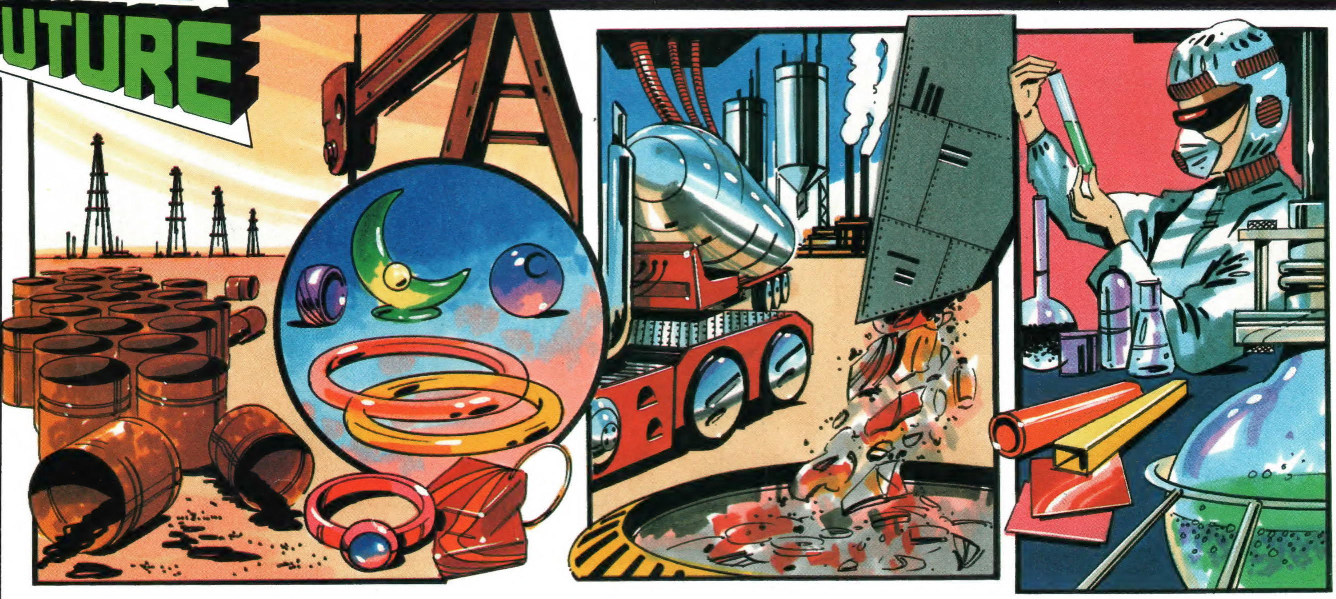
Polycarbonate is also transparent and is much stronger than acrylic. It is used to make riot shields, bullet-proof partitions in banks, and babies' bottles. Like acrylic, it can be coloured and used to make safety helmets and computer parts.

Plastics are used in liquid form to provide other materials, such as metal or paper, with a protective coating. Paints and varnishes often contain thermosetting resins, which dry to give a very hard finish.

Some plastics are used as glues. They can be made soft and sticky by either heating them or dissolving them in suitable solvents. Solvent-based glues include polystyrene cement and rubber solution, which is used to mend bicycle tyres.

INTO THE FUTURE

WHEN OIL RUNS OUT



▲ *As the world's oil supplies begin to dwindle during the next century, making plastics from oil by-products will become too expensive.*

▲ *Manufacturers will have to use recycled packaging to an even greater degree, making raw materials go further and further.*

▲ *Eventually scientists will harness microbes to build new plastics from waste products, churning out new materials from a 'chemical soup'.*

Joe Lawrence

COUNTER TERRORISM

AS BOMB ATTACKS shootings and political kidnappings become gruesome facts of life, the world's security forces are increasingly reliant on advanced technology to combat ever-changing terrorist tactics and weapons.

Some of the greatest advances in counter-terrorist technology have

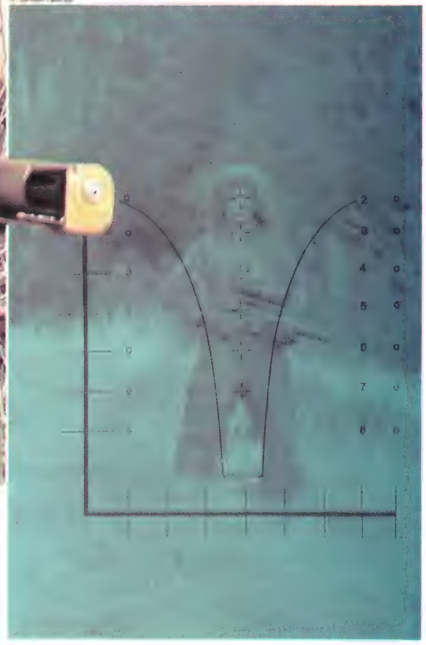
Rex Features Ltd

***Terrorist bombs** planted in cars and on planes have claimed countless lives worldwide, despite improvements in explosive detection devices.*

Gamma/Frank Spooner Pictures

E Nevill/TRH Pictures

Image-intensification sights *can be attached to rifles, enabling the soldier to see his enemy in the dark (below). The lens enhances low-level light by more than 85,000 times.*



USMC/TRH Pictures

been in the area of advanced surveillance equipment. For example, long-range cameras, which can be mounted on the underside of a helicopter, are used for monitoring the movements of suspected terrorists. Cameras and rifles can also be fitted with image-intensifiers, which electronically amplify low-level light, allowing security forces to see their enemy at night. High-powered searchlights can also be attached to helicopters for night surveillance. These can pinpoint and illuminate a small area from high altitude, thus reducing the threat of small arms fire. The searchlights can be fitted with a special filter to observe activities at night without a terrorist knowing the beam is directed at him.

RADAR SNIPER-TRAP

One of the most difficult things for a soldier to work out is the direction from which he is being shot at. This is particularly difficult in towns where shots tend to echo and re-echo around buildings. But a radar system called Claribel can indicate to within a 30° arc where the bullet was fired from. The equipment can be fitted on to armoured vehicles, or carried in a flak jacket. It detects missiles of all velocities except stones and bricks. The direction of fire is indicated on a simple luminous clockface display. The system can also indicate the positions of two separate snipers firing simultaneously.

Spy in the sky

Satellites are also used in the fight against terrorism. American satellites have been used to observe bomb factories in 'hostile' countries such as Libya, and to monitor illegal arms shipments to terrorist groups around the world.

At international airports, improved baggage screening systems, using the latest X-ray technology, have reduced the likelihood of hijacking.

Machines that can detect explosives have also frustrated many terrorist actions. Most explosives emit vapour, which can be analysed by electronic 'sniffing' machines. However, more and more terrorist groups are using odourless plastic explosive, such as Semtex, which cannot be detected by sniffer dogs or by X-ray machines.

Armoured vehicles

Internal security (IS) vehicles are standard wheeled armoured vehicles, only with a number of different attachments added to make them suitable for operations in a counter-terrorist or riot situation. These can be water-cannon, 'cow-catchers' to remove barricades, searchlights, electrification systems to prevent a mob climbing on to the vehicle and tear-gas dispensers. IS vehicles are often modified to make them more suitable for an urban environment. For instance, they are given an extra door in the side to allow the crew to get out quickly in an emergency or are fitted with sloping roofs so that bombs thrown from rooftops will roll off.

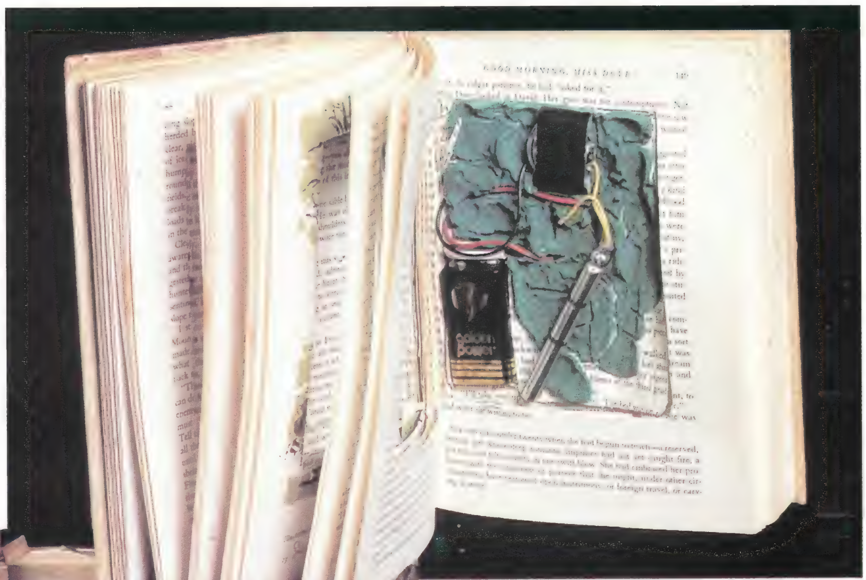
Distant danger

Remote-controlled vehicles have been developed that enable the Ammunition Technical Officer (ATO) to remain at a safe distance while he locates, identifies and monitors a suspected bomb (all this is done via a TV screen). If he decides that the object is too dangerous to approach, he can attempt to disarm or destroy it by

Surveillance systems, *with infra-red sensors, TV monitors and remote-controlled cameras, protect military and government installations from terrorist attack.*

Group 4 Ltd

using the 'Wheelbarrow'. This is a radio-controlled device for defusing bombs, which has been developed and refined by the British Army since the start of the Troubles in Northern Ireland. The Wheelbarrow can be adapted to deal with different types of target. It has a closed-circuit TV camera and monitor, lights to illuminate the target and an automatic rifle that fires a 'disruptor' projectile at the bomb to break up its circuits and fuses. It also has a telescopic boom for examining bombs planted in inaccessible places such as petrol tankers – a favourite IRA target. With the latest additions it can even carry and automatically fire a variety of weapons used in riot, hostage or 'shoot-out' situations.



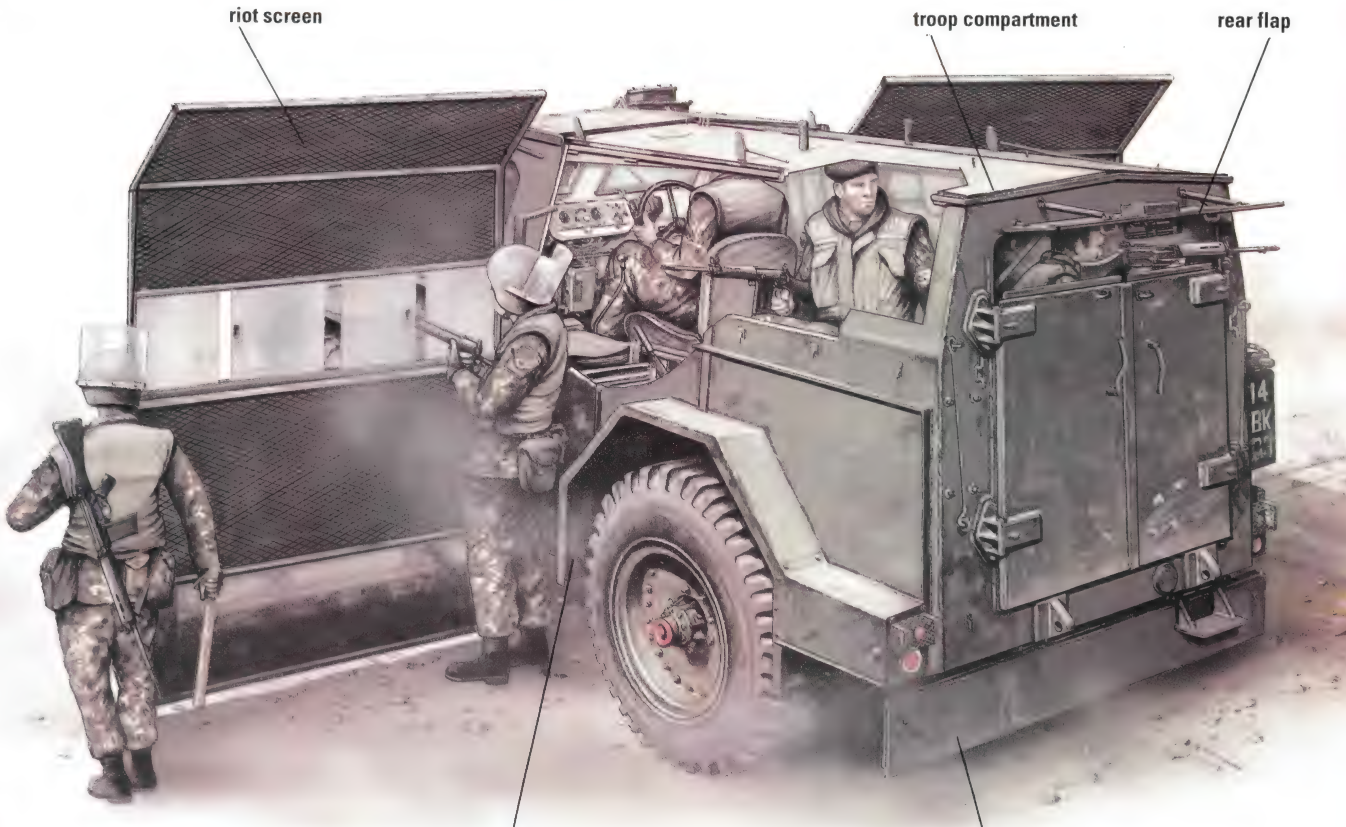
Gamma/Frank Spooner Pictures

SIPA/Rex Features Ltd

__'The Pig'__ – the Humber 1-tonne armoured personnel carrier – was brought back into service as an anti-riot vehicle on the streets of Northern Ireland. As the IRA's weaponry grew more sophisticated, the vehicle was reinforced with extra armour plates.

***Massive hauls** of bomb-making equipment and arms have frustrated terrorist actions but even small amounts of explosive (above) can prove deadly.*

On some occasions, the bomb-disposal officer will have to approach the suspected bomb himself, either to prevent blast damage or because forensic evidence is required. In such a case, he will wear an EOD suit, made of ballistic nylon, which is de-

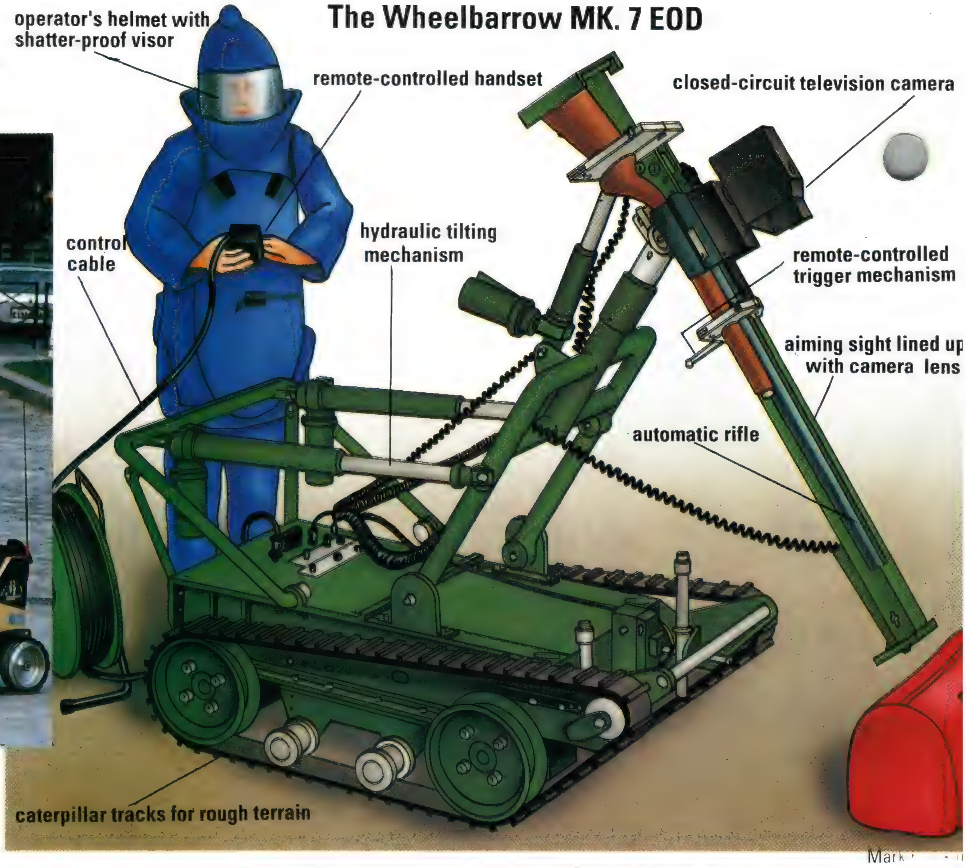


Inside The Pig

Aerospace Publishing

***This radio-controlled bomb** disposal vehicle is equipped with closed-circuit television and X-ray equipment to examine suspect packages (below).*

Labat/Lanceau/Jerrican/SPL



signed to give some protection against fragments, blast and flames during the disarming of improvised explosive devices (IEDs). The minimum requirement for such suits is that they withstand a 250 gm nail-bomb at a distance of 0.9 metres.

Bomb blanket

Security personnel can also be protected from the full blast of a bomb by covering the explosive with a bomb-suppression blanket. Made of fire-resistant ballistic nylon and Kevlar, the blanket reduces the pressure of an explosion.

Anti-terrorist squads such as the Special Air Services (SAS) have a wide variety of assault equipment at their disposal when called upon to intervene in a terrorist situation. One of these, the stun grenade, first came to the public's attention in the October 1977 Mogadishu hijack in Somalia, when the SAS provided technical assistance (and stun grenades) to the German anti-terrorist squad GSG 9. They were also used in May 1980 by the SAS during the storming of the Iranian Embassy in London. The purpose of the grenades is to shock the terrorist into temporary inactivity and to distract him while entry is gained to the building or aircraft in which hostages are being held. The grenades produce one or more ear-splitting detonations and a blinding flash. Although stun grenades are designed to be non-lethal, their premature detonation could severely injure the thrower.

The general category of assault equipment also includes tear-gas (CS) grenades and launchers, sniper rifles, lightweight assault ladders, grappling hooks and helicopters specially adapted for landing anti-terrorist troops.

***A bomb-disposal van** contains a wide range of equipment, including bomb-protection suits and helmets, portable X-ray equipment, under-vehicle inspection mirrors, bomb-disposal tools and tripod-mounted lights.*

A I Security

Paul Raymonde

Eye-dentification

Identification of suspected terrorists will soon be made easier by eye scanning. Every person has a unique and unalterable eye pattern. A retina scanner can identify a person by bouncing an infra-red beam against the back of the eye and reading the pattern of blood vessels. These scanners should soon help bring terrorists to justice.

STRATEGIC BOMBERS · LOW-LEVEL ATTACK · STEALTH

BOMBS AWAY!

DOD/TRH Pictures

***Small 'strike' aircraft** carry bombs for use against ground troops and military targets. They can be just as effective as the huge bombers that reduce cities to rubble.*

WHEN MISSILES WERE developed that could deliver nuclear warheads deep inside enemy territory, the days of the manned bomber seemed to be numbered. However, the USA, Russia and many other nations have continued to develop their strategic bomber fleets.

Manned bombers have many advantages over guided missiles. Once launched, they can be recalled. They can be armed with a much greater variety of weapons and used in counter-insurgency operations or conventional limited warfare – in addition to all-out nuclear war. Missiles are effective deterrents, but they are really only weapons of last resort and so only have limited uses.

Heavy bombers are strategic weapons whose targets are often cities and towns far removed from front-line fighting. Warring nations have long since abandoned the fiction that enemy civilian casualties are the unfortunate by-product of attacks on war factories in built-up areas. The medium and long-range bomber is, by threat or direct action, intended to crush a nation's will to resist by inflicting massive damage to major cities and huge civilian casualties.

Heavy bombers

The Russian air force is equipped with a wide range of bombers. Most remarkable of all these, perhaps, is the seemingly old-fashioned propeller driven Tupolev TU-95/142 'Bear'. Although it first flew in 1954 it remains in production to this day. It is the heaviest of the serving Russian bombers and has the immense radius of action of 8285 kms. It is also used for long range reconnaissance duties and was regularly intercepted and shadowed by NATO Phantoms and Tornados fighter aircraft over the North Sea.

Other serving Russian bombers are the TU-16 'Badger' and TU-22 'Blinder'. Both are jet aircraft and the

Mi Seitelman/IDI

***The Fairchild A10 Thunderbolt** is a 'close-support' aircraft, destroying enemy positions without damaging nearby friendly forces.*

Blinder was the Russians' first supersonic heavy bomber.

One of the most impressive of heavy bombers, however, is the TU-22M 'Backfire' which is capable of flying at speeds of up to Mach 2 – that is, twice the speed of sound. But the latest Russian heavy bomber is the Tupolev 'Blackjack', which has recently come into sevice with the Russian air force. This combines a Mach 2 dash performace with the range to fly a two-way mission against targets of America from Russian bases inside the Artic circle.

The United States Air Force has been equipped with the Boeing B-52 bomber since 1955 but it has been continually updated. It is now capable of low-level penetration and armed with air-launched cruise missiles. It remains the world's longest range bomber.

Variable geometry

The latest US bomber to go into service is the Rockwell B-1B. This is a variable-geometry aircraft with a maximum top speed of Mach 1.25. Some one hundred of these aircraft have been ordered by the United States Air Force and should be in service soon.

Bombers do have their problems though. They are large aircraft that must operate over enemy territory, making them a target that is easy to detect and difficult to protect. Radar systems can 'see' bombers approaching and direct interceptor aircraft and anti-aircraft fire towards them. And the development of effective surface to air missiles have made high-altitude bombing out of the question.

To counter this, new bombers are designed to fly low and fast – below the enemy's radar coverage. This meant equipping the aircraft with terrain-following radar – so that the plane can follow the contours of the ground below – and cockpit information systems with 'head-up' displays so pilots are able to read their instruments and look out of the cockpit window at the same time. This is very necessary when flying just 30m above the ground at speeds that leave no margin for error.

Low flying

Flying at very low levels also puts enormous stresses and strains on the airframe, so the new generation of low-level bombers has to be built particularly strongly. Low-level flying requires enormous skill. The training is lengthy and extremely expensive. A large number of pilots are killed and many aeroplanes are lost in training accidents.

Another way around the problem of flying into enemy air space is to equip bombers with a 'stand off' capability, that is the ability to launch a cruise missile at a target from outside the enemy's main defences. Air-launched cruise missiles are now

DOD/TRH Pictures

***The 'Bear'**, the huge Tupolev TU-95, can fly at up to 925 km/h – faster than was once thought possible for a propeller-driven plane.*

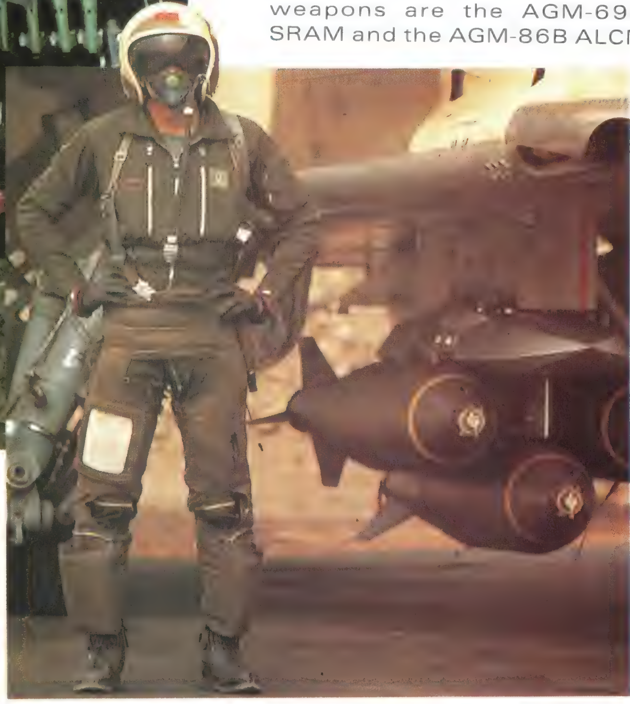
***Purpose-built** strategic bombers have huge bomb bays. Smaller 'attack' aircraft have their weapons slung below the airframe.*

Gamma/Frank Spooner Pictures

***The neutron bomb** is a much more effective tactical weapon than a conventional nuclear bomb. Its greater radiation kills many more troops, even though its blast is considerably smaller.*

Joe Lawrence


British Aerospace


Alain Ernoult & Ernoult Features/IDI

A small 'attack' aircraft, such as the Jaguar, carries a huge array of weapons. During their training to fly low and fast many pilots (inset) are killed.

approaching the same accuracy as bombs delivered closer to the target but may still go astray.

The ideal solution is to design an aircraft that can fly wherever it wishes and still not be seen by radar. This is the thinking behind the Northrop B-2 'Stealth' bomber, which was unveiled in late 1988. By rounding off all corners and using non-metallic materials, there is little for radar waves to bounce off.

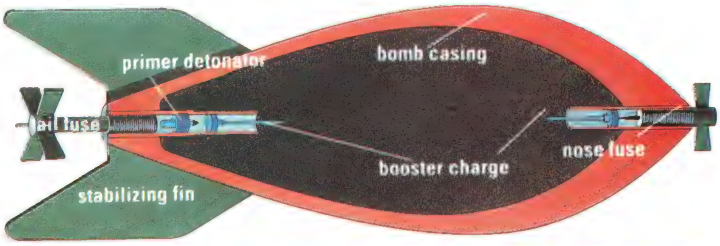
Invisible

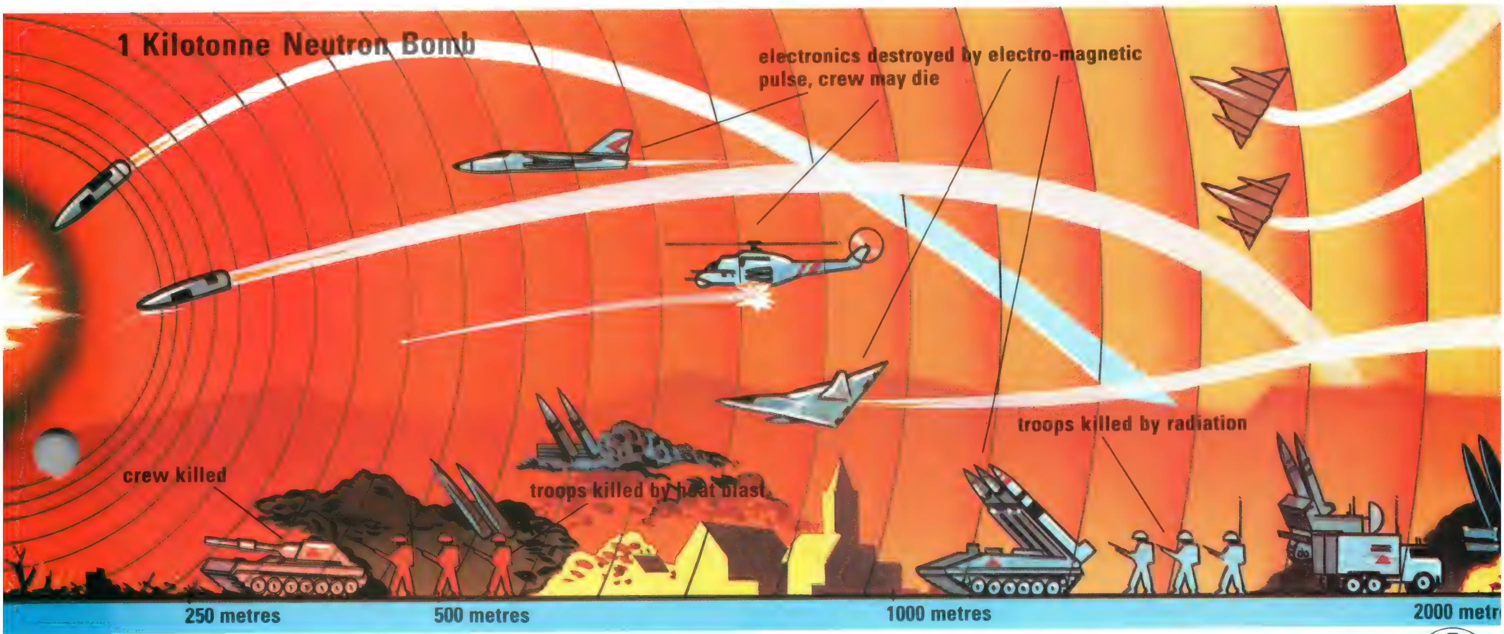
The B-2 is also designed to be very quiet so it is hard to hear and to give off a minimum of exhaust smoke and vapour trail so it is hard to see. The amount of heat it gives off is also minimized, making it difficult to spot using infra-red detectors. As a result, the B-2 is an incredibly expensive aircraft and only a very few have been produced for use in special circumstances.

Cruise missiles

While free-falling bombs are still used by modern air forces for close support of ground troops, the superpowers rely to a great extent on air-launched cruise missiles so that the aircraft do not have to overfly heavily defended targets. Principal US weapons are the AGM-69A SRAM and the AGM-86B ALCM

A general purpose bomb is designed to explode in the top floors of buildings. The firing pin is screwed into the booster charge by the propellers as the bomb falls.





THE ANTI-AIRFIELD MINE – A HIDDEN THREAT

Hunting Engineering Ltd

The HB876 is an 'area denial mine' that is designed to disable airfields. Some 430 of these tiny mines are dropped in a canister with 60 'cratering' bombs – explosive devices designed to cause huge craters in runways. The canister opens as it falls from the plane, cratering the runway and the rest of the airfield. The mines are scattered around the edge of the craters, going off when approached or automatically at random intervals. Each mine contains two warheads, one to destroy bulldozers or armoured clearance vehicles and one fragmentation charge to kill anyone nearby. The combination of craters and mines keeps the airfield out of service for a very long time.

Paul Raymonde

which has a range of up to 2500 km. The Russians use AS-3 'Kangaroos', AS-4 'Kitchens' and AS-6 'Kingfishers'. The longest reach that can be achieved by the systems is 650 kms, but the latest Russian ALCM, the AS X-15, will give the 'Bear', the

Once a cluster bomb (1) has dropped clear of the aircraft, the outer skin strips away (2). An inflating bag ejects them and tiny parachutes slow each bomblet (3).

1

'Backfire' and the 'Blackjack' bombers a stand-off range of some 3000 kms.

One of the most common purposes to which military aircraft are assigned is the assault upon the enemy's ground forces and ground installations. Most of the world's air forces possess aircraft of this type, which are normally classified as 'strike' or 'attack' aircraft.

Strike and attack

Attack is usually taken to mean a sortie against forces close to the front line or in the immediate rear area of the battlefield. Strike missions on the other hand are aimed at targets further away and can involve the use of nuclear weapons.

In this respect the strike aeroplane has some overlap with the duties of the heavy bomber. Typical targets for tactical strike/attack aircraft would be airfields and supply lines, with the aim of starving the front line of all forms of support and forcing troops to retreat without fighting. The United Kingdom and France rely on the Jaguar to provide part of their tactical nuclear strike capability, even though this aircraft is not truly all-weather. The Jaguar has an Inertial Navigation System that is allied to a pilot's moving map display, but it can end up more than 1.6 kms off target.

Terrain avoidance

No such limitations affect the Panavia Tornado, which is equipped with an automatic terrain following radar suitable for flying at 30m over enemy territory, day or night. This is an improvement on the terrain-avoidance radar fitted to aircraft such as the American F-111 which provides only a warning of obstacles ahead as a result of which pilots have to take rapid evasive action.

As well as navigation aids, strike aircraft

2

are equipped with a package of penetration aids, including electronic jamming equipment to confuse enemy radars, chaff and flare dispensers to decoy surface-to-air missiles and self-defence air-to-air missiles to take on and destroy any enemy interceptor aircraft.

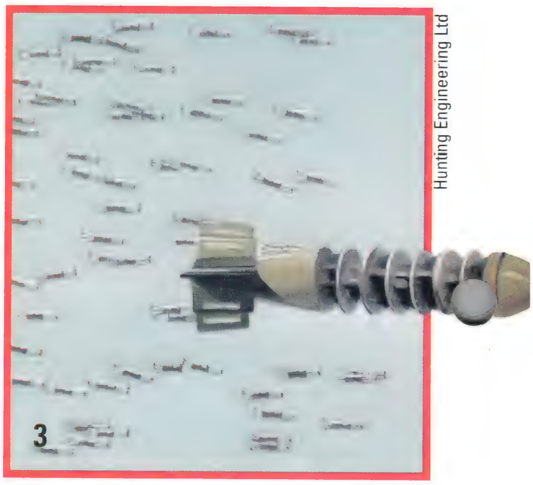
Backseaters

The more advanced strike aircraft have two crew members, one of whom is the backseat weapon systems operator – or backseater – responsible for operating all the aircraft's electronic systems. The weapon carrying capability of attack/strike aircraft ranges between the Sukhoi Su-7 Fitter's 2500 kg and the Fairchild A-10A's amazing warload of 7258 kg. Armament options normally include a cannon of 20 mm or 30 mm calibre and the full range of bombs, rocket pods, cluster bombs and occasionally air to surface – or SAM – missiles.

Cluster bombs

Cluster bombs are essentially a container filled with hundreds of 'bomblets'. These might be designed to penetrate the top armour of a squadron of tanks or be scattered the length and breadth of an enemy airfield runway, giving the enemy the problem of disposing of hundreds of bomblets before they can use the runway again.They are also vicious anti-personnel weapons that can kill, maim and injure large numbers of people in one go.

Despite the thaw in the Cold War, weapons like these – along with conventional incendiary and high-explosive bombs – will still be used in the hundreds of small-scale wars that are waged around the world.



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Hunting Engineering Ltd

GUN SHIPS

© Frederick Sutter 1990

Attack helicopters *such as the Apache AH-64 are formidable weapons systems, capable of destroying main battle tanks over 1 kilometre away. The Integrated Helmet and Display Sighting System (above) allows crew members to aim at targets just by looking at them.*

ARMED TO THE TEETH WITH anti-tank missiles, line-of-sight rockets and rapid-firing heavy machine guns, skimming trees at 320 km/h and capable of turning in its own length, the modern attack helicopter not only reaches the targets that other aircraft cannot – it destroys them.

Helicopters were first used on the battlefield for carrying troops from one location to another, for casualty evacuation and for scouting and observation. When the enemy started shooting at them, light armament was fitted for defensive purposes. It was soon realized that the helicopter was the ideal firing platform for wire-guided anti-tank missiles. These first 'attack helicopters' or 'gunships' were essentially utility machines with 'strap on' offensive missile systems.

Huey Cobra

The first real attack helicopter was the AH-1 Huey-Cobra. Although this aircraft first entered service with the US Army in 1969, it is still in use, with US forces and other armies.

The Cobra is a slim, sleek and fast attack helicopter. The pilot and weapons operator sit one behind the other. The resulting narrow profile of only 91cm allied to low cabin height makes the AH-1 more difficult to hit with small-arms fire and easier to camouflage on the ground. It carries a combination of 'mini guns' firing thousands of rounds per minute and 40mm grenade launchers in the nose turret with rockets and gun pods on the four pylons attached to the stub-wings. The turrets are 'slaved' to the cockpit weapon sights.

Alain Ernoult & Ernoult Features/IDI

Mi Seitelman/IDI

Paul Raymonde

Mi Seitelman/IDI

***The pilot's view** of the Bell AH-1 Cobra (right). The crew compartments are armour-plated, capable of protecting the pilot and gunner from hits by 12.7mm armour-piercing rounds.*

This means that if the weapons operator looks at a target not directly on the flight path and presses the firing button the miniguns will automatically train on the target irrespective of which direction the helicopter happens to be flying in.

The present attack helicopters are even more impressive. The US AH-64 Apache is larger, heavier and much more powerful than the Cobra. It has a top speed of 296 km/h and is armed with a chain gun 30mm cannon carried under the forward fuselage with a maximum of 16 Hellfire anti-tank missiles on the four weapon stations on the stub wings.

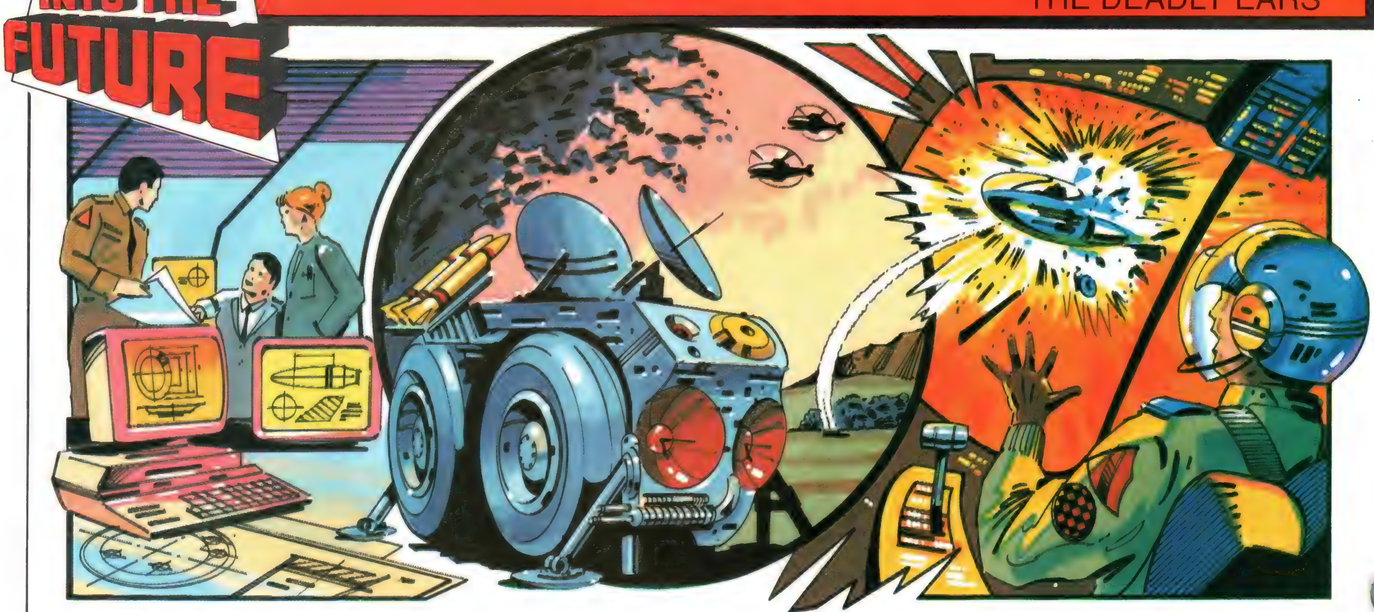
The Apache's avionics include target acquisition and designation sights (TADS) carried in a rotating ball turret on the nose of the aircraft.

Sighting targets

This is a computerized targeting system, allowing enemy forces to be selected and 'sighted' while the helicopter is concealed. In addition, the Apache has thermal imaging equipment to allow the pilot to fly at low level at night or in bad visibility. It is also equipped with passive radar and laser warning receivers so that the pilot knows if he is under attack, infrared and radar jammers and chaff (metal foil radar decoy) dispensers.

INTO THE FUTURE

THE DEADLY EARS



...Lawrence

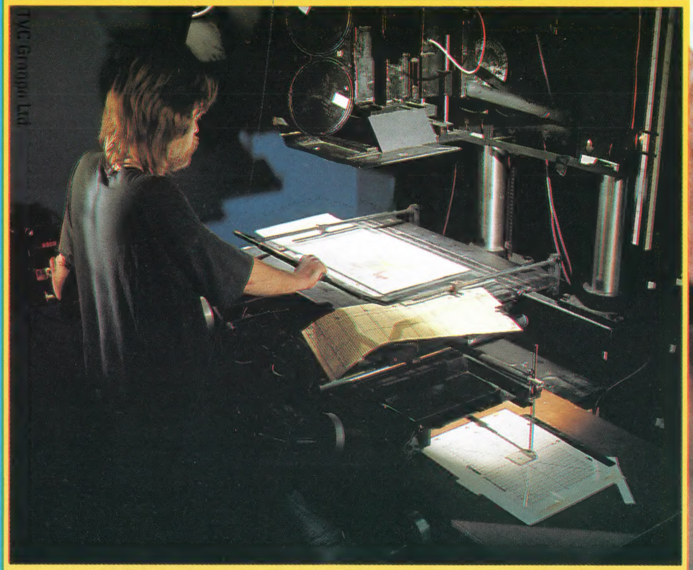
▲ The latest battlefield weapons system under development is the intelligent 'helicopter mine', designed to secure an area against enemy air movement.

▲ The weapon will 'listen' for helicopters with an array of microphones, identifying an enemy aircraft by the unique frequency 'signature' of its main and tail rotors.

▲ An onboard computer will determine the position and flight path of its target, then unleash a homing ground-to-air missile, destroying the helicopter.

- STORY BOARDS
- PHONEMES
- LINE TESTS

DRAWING POWER


TVC Graphics Ltd

Kobal Collection

ANIMATION IS THE ART OF the impossible. Anything can happen – elephants fly, rabbits talk, and magic is normal. But the most impossible thing of all is that nothing in animation ever actually moves.

Animation is possible because the brain interprets a series of still pictures flashed on a screen at a rate of 24 frames a second as a single image. If each image is slightly different from the one before, the illusion of movement is made.

But certain conditions have to be

Who Killed Roger Rabbit? *used computer technology to marry cartoons and live action. But the animation was shot the old fashioned way, frame by frame on a rostrum camera (inset).*

met. The jump between pictures must not be too big and the time between each jump must not be too long. Getting these things right is the art of animation.

Animated films are shot frame-by-frame. This means that the image – a picture or an object – is shot then moved or changed in some way and shot again.

story board. This is like a comic strip version of the script. It shows the action, dialogue and camera shots. This is acted out to give the timing of each scene. When the timing is right, the voice track is recorded.

The animatic

The storyboard is then shot on a single-frame video recorder and the sound track added. The resulting tape is called an animatic. Although it only contains still pictures, the animatic gives a very good idea of how the final film will look. But changes can still be made quickly and cheaply.

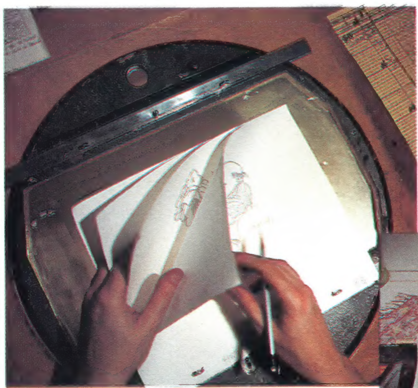
The animatic not only shows what the film will look like, it shows what backgrounds, sound effects and special effects might be needed. All of this has to be worked out very accurately before the film goes into production.

When the voice track has been finalized, the editor does a breakdown of the speech, splitting words up into 'phonemes' or individual sounds. The word 'hello' has two phonemes 'ha' and 'lo'. They have different lip shapes.

MAKING THEM MOVE

There are three major techniques of animation which are used in cartoon films and combined with live action to produce special effects in horror, adventure and science fiction films:

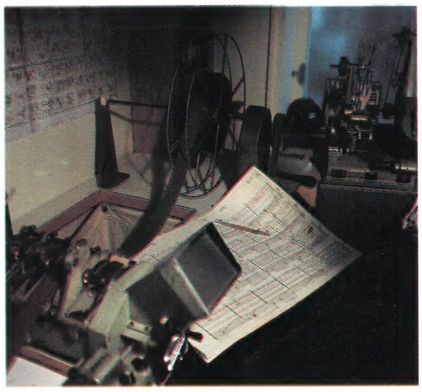
- Drawn animation covers those methods that use a series of drawings, with one replacing the next. These images are usually drawn on paper or clear plastic, but could also be painted on a canvas, chalked on a blackboard or drawn on a computer screen. Drawn animation is the most expensive method, but offers the most control. Mickey Mouse is drawn animation
- Cut-out animation uses flat cut-out shapes normally made of cardboard. The shapes can be hinged to create the movement as with the arms and legs, or the shapes replaced by other shapes that are slightly different. This method is quick and cheap, but very limited.
- Model animation uses 3D figures and objects. These can be puppet figures or modelled from plasticine.



TVC Granpa Ltd

Line drawings of the major elements of the shot are assembled to check that everything is in the right position. The coloured foreground image (right) is produced on clear plastic so that the background does not have to be redrawn.

The 'rushes' – raw footage straight from the camera – are viewed in the cutting room. When the film has been edited, the pictures and sound have to be synchronized (below). The bar sheet gives a detailed breakdown of every single element of sound.



In the first or pre-production stage, the director works closely with a scriptwriter and designer. The scriptwriter has to create a story that is visually suitable for animation, while the designer has to create characters that can easily be animated. They must not have too much detail as each detail has to be redrawn thousands of times.

The characters are first worked out as personalities. The way they move and talk, the way they dress and the things they do are drawn out on a model sheet which is the guide for the animators.

The next stage is to draw up a

Just amazing!

ARTISTS' NIGHTMARE

TO PRODUCE A FULL-LENGTH 90-MINUTE CARTOON FEATURE FILM, FROM STORY BOARD TO THE FINAL MOVIE, CAN TAKE OVER 1 MILLION DRAWINGS – THAT IS OVER 11,000 A MINUTE.

Paul Raymonde

Bar sheets

The editor records where the sounds start and end on 'bar sheets', which are timed in frames. A frame is 1/24th of a second and the word 'hello' lasts 20 frames. The animators need to know exactly where the phonemes start and end so that they can draw in the right mouth shapes.

If the animation has to be timed to the sound effects – footsteps, door knocks, the thunder of hooves – or music, these sounds have to be recorded before the animation starts. But other sounds – a single crash, background music – can be added afterwards to fit the animation.

The layouts

While the editor is doing the sound track breakdown, a layout artist uses the storyboard as a guide to do the layouts. These are large sketches of scenes showing the background and the character positions within each scene. The layouts help the animator to plan the movements.

When the animators start work, they will sketch out the animation as pencil line roughs. These are then shot as a 'line-test' to check the timing and the movement of the animation. Many commercial studios use sophisticated computerized line-test machines. These systems save a great deal of time as they allow the tests to be shot and replayed immediately. They also let the animator change the speed of a movement, add and subtract frames, move scenes around and store the results –

all without having to cut film or reshoot a single frame.

While the animators are working on the action, other artists are working on the backgrounds, titles and effects like rain and snow. These are specialized areas of artwork often done by painters and illustrators. Large animation studios employ a range of artists with different skills.

When the animation has been line-tested and corrected, the pencil drawings are then traced on to a clear plastic sheet called a cel and painted. They are numbered in sequence and listed on a 'dope sheet' ready for the cameraman to shoot.

The purpose of using a cel is that a drawing can then be made up in parts. The head, body, arms, legs and face can all be drawn on separate cels and overlaid, then only the action part of the drawing needs to be redrawn to create movement. For example, a man only needs to have the sequence of legs redrawn to make him walk.

Shooting single frames

When each scene is complete, it is checked to make sure all the drawings are in the correct sequence with their proper backgrounds. They are then sent to the cameraman. The drawings are photographed on a specialized animation camera that is designed to shoot single-frames.

These 'rostrum' cameras have a column that the camera can move up and down on to produce a zooming effect as the camera moves in and out of the scene. Panning effects – moving across the scene or up and down – are done by moving the table the cels sit on under the camera.

'Mixes' and 'fades'

The computer can also control the camera lens so that 'mixes' – from one scene to another – and 'fades' to black can be programmed as well.

In the film *Who Framed Roger Rabbit?* the problem was to make the animation seem to be part of the live-action scene. To do this meant

SVC Television

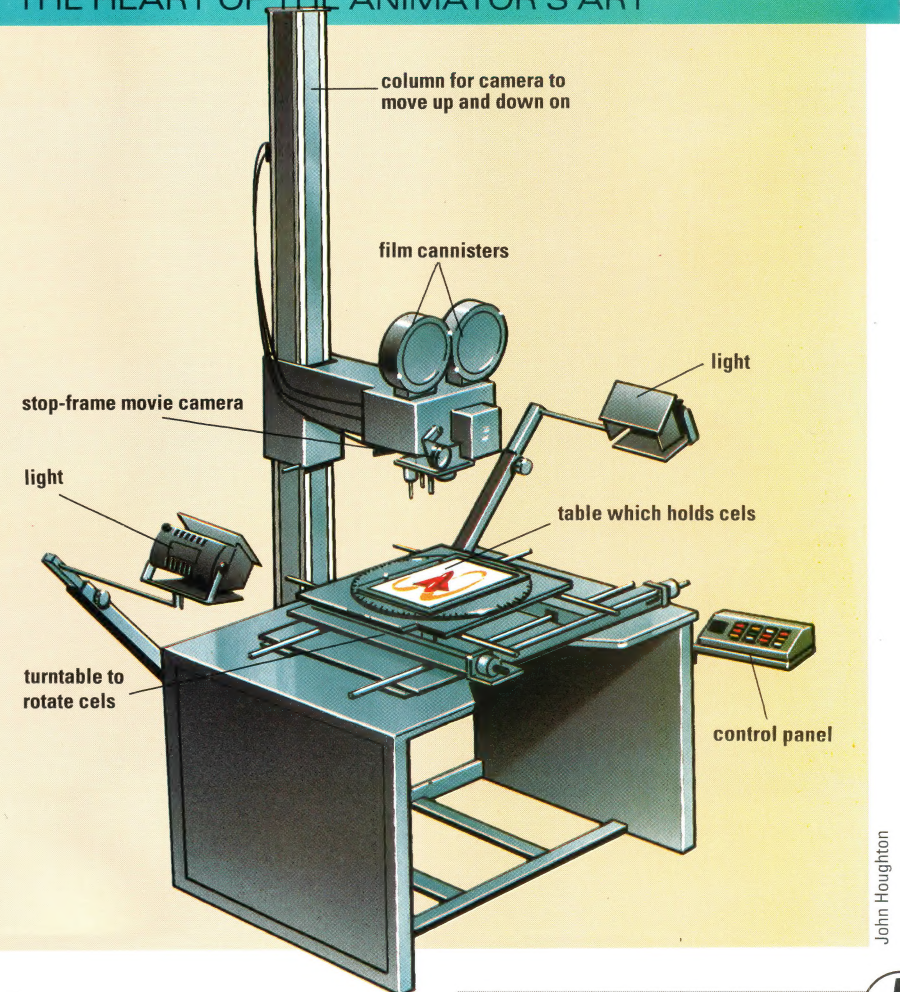
***Television cartoons** are usually made on film, then transferred on to videotape in a colour correction suite.*

THE ROSTRUM CAMERA – THE HEART OF THE ANIMATOR'S ART

The rostrum camera shoots the drawings that make up a cartoon film, frame by frame. The clear plastic cels – each carry elements of the background, foreground and characters – are laid on the camera's table, layer by layer, held in position by pegs.

Elements of the character cel can be changed and the background cel moved, shot by shot, to create the impression of movement. But to make a cartoon film even more life-like – or more like a conventional movie at least – the camera needs to zoom in and out of the action and pan across it. To create a zooming effect, the camera is moved up and down on the column. And to create panning, the cels on the table are moved from side to side or rotated under the camera.

One of the problems with rostrum cameras is vibration from traffic. Many are installed in the basements of buildings to minimize this effect.



John Houghton

shading the cartoons to give a 3D image and light and shadows that were consistent with the live-action people. A technique called computerized 'ray-tracing' was used. The computer selected the sources of light in a scene and worked out how the patterns of light and shadow would fall on a solid in its path.

When the film has been shot, it is sent to the laboratories for processing. The laboratories keep the processed negative and send a print back to the studio for editing. This is called a cutting copy because the editor uses it for cutting when matching the film to the voice track.

When the cutting is complete, the picture and the three separate voice, music and effects soundtracks are run together in a dubbing theatre. The sounds are adjusted to fit the action in the pictures, then dubbed or mixed together on a single track.

SVC Television

***In special effects animation** a special camera is used that shoots both on film and on video tape. This makes it easier to blend in cartoon sequences.*

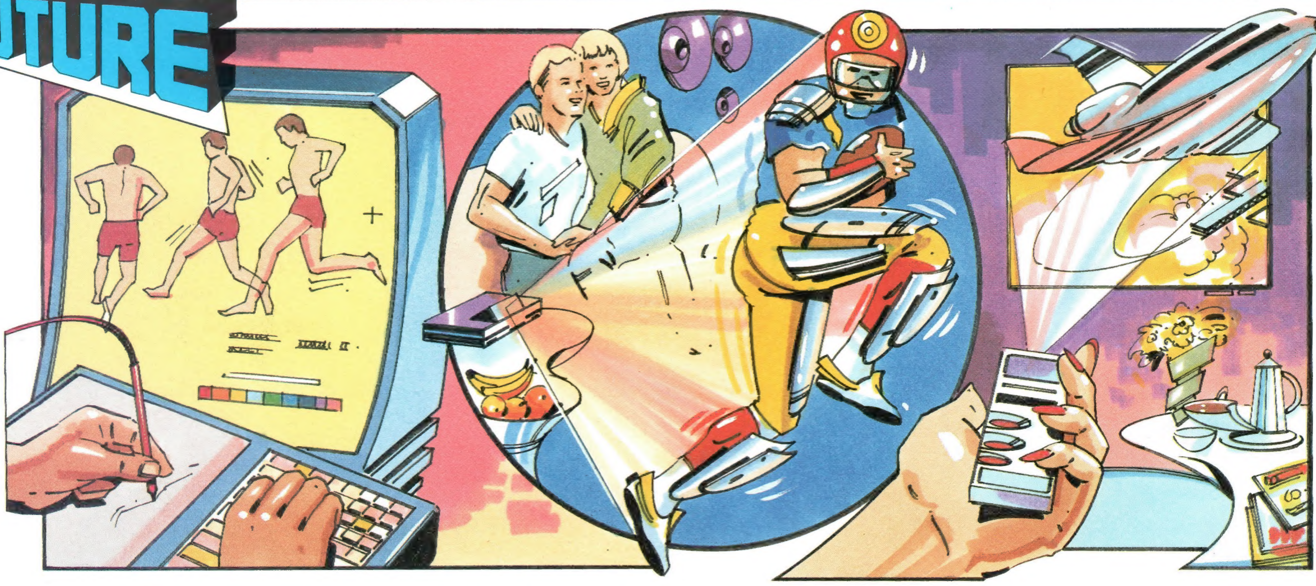
Hasbro &Sunbow Productions Inc/Ronald Grant Archive

***All the elements** work together to make an exciting film with lots of 'action' produced by thousands of still pictures.*

The completed soundtrack and the edited picture are sent back to the laboratories, where the original negative is cut to match the edited version. The soundtrack is transferred from magnetic tape to the optical track of the film. The sound and image are then combined on a single piece of film ready for projection.

INTO THE FUTURE

FANTASY INTO REALITY



▲ Already a computer 'paintbox' can be used to manipulate images. It should soon be possible to build up enough images of an actor to animate a 'real' figure at will.

▲ 3-D TV already allows an image to move around in a confined space. So an animated actor or a cartoon figure could be made to walk around your living room.

▲ As paintbox technology becomes more widely available, it may be possible for you to control your own interactive animated films at home.

Joe Lawrence